# Navigation Alternatives
# Technical Analysis Results

**Kelly Markin**

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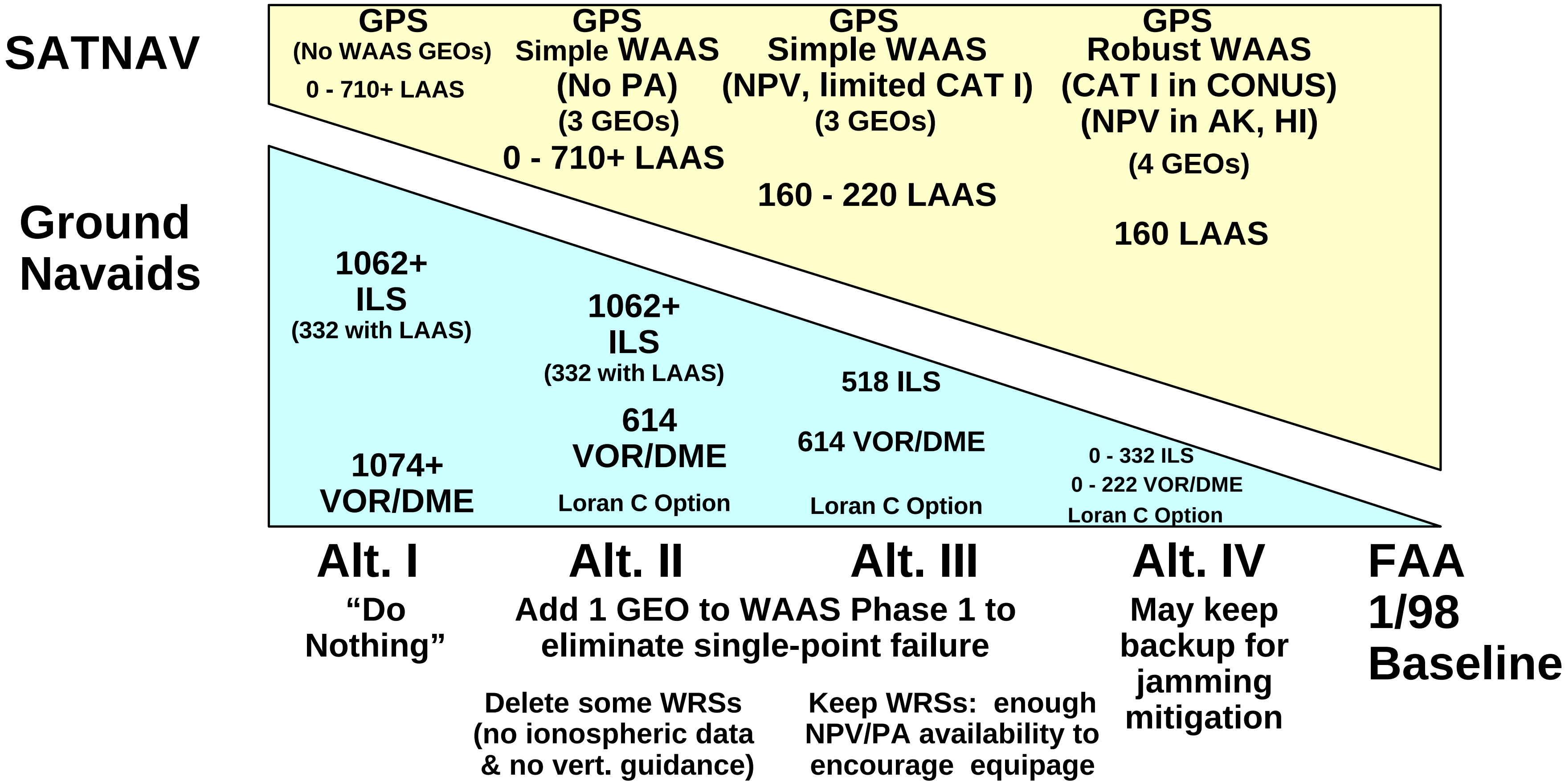
# Outline

- Objectives/outputs of performance assessments
- Review of and changes to the alternatives
- Refinements and next level of detail
  - Role for LAAS
  - Incorporation of JHU/APL study results
  - Relationship to NAS Architecture Version 4.0
  - GPS JPO input on better GPS satellite availability
- Performance assessment results
- Recommendations for cost and benefits analysis

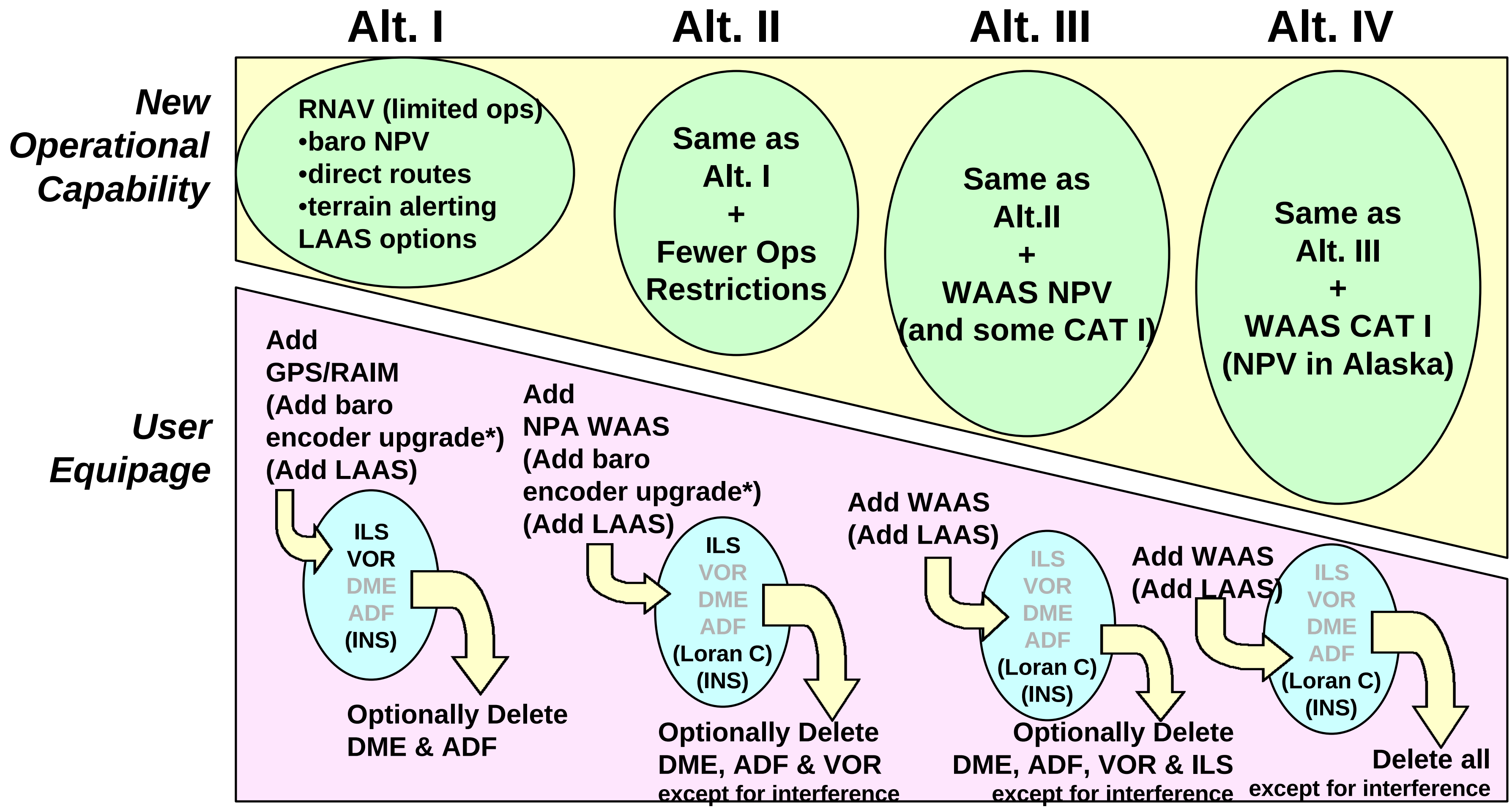
# Objectives and Outputs

- **Objectives of the performance assessments:**
  - **Eliminate untenable combinations**
  - **Provide enough detail so that:**
    - **Cost Team can develop appropriate numbers**
    - **Benefits Team can distinguish between alternatives**
- **Outputs:**
  - **Numbers and quality of satnav and ground assets**
  - **Implications on avionics equipage**
  - **Operational capability**

# Review of Alternatives: Government-Provided Functionality



# Review of Alternatives: Operational Capabilities and User Equipage




*Baro NPV is the means for Alternatives I and II to meet FAA's safety goal for approach procedures with vertical guidance for instrument approaches without ILS or LAAS

# Role of LAAS

- **For January 1998 Baseline**
  - **143 LAAS: 85 CAT II/III LAAS (to replace the current CAT II/III ILSs plus growth) and 58 CAT I LAAS (to supplement CAT I WAAS availability)**
- **Alternative IV**
  - **Approximately 160 LAAS: Same as for 1998 baseline plus about 17 additional CAT I LAAS in Alaska and Hawaii**
- **Alternative III**
  - **Approximately 220 LAAS: Same as for Alternative IV plus additional CAT I LAAS for 200 busiest airports (depends on WAAS CAT I availability achieved with new iono algorithms and future GPS constellation)**

# Role of LAAS (continued)

- **Alternative II**
  - **No LAAS (sustain ILS for all precision approach)**
  - **OR, 710 (plus growth) LAAS to replace all ILS precision approaches (except for those ILSs needed for GPS interference mitigation or international commitments)**
- **Alternative I**
  - **0 or 710 plus growth (same as for Alternative II, except may need to use pseudolites to achieve availability without GEOs)**
- **Possible use of ELAAS (e.g., in Alaska, Hawaii) being explored in technical analysis**

# Incorporation of Johns Hopkins University/ Applied Physics Lab (JHU/APL) Study*

- **JHU/APL studied ability of GPS/WAAS/LAAS to achieve "sole means" navigation, particularly for outages due to GPS radio-frequency interference**
  - **Addressed law-enforcement procedures (applications including non-aviation) and radar procedures**
  - **Identified airborne mitigation techniques that could make it feasible to delete ground-based backup**
    - **Phased-array GPS antennas/processing**
    - **GPS receiver filtering/processing techniques**
    - **Integration of GPS sensor with inertial navigation**
- **The technology implications were reviewed and incorporated into this alternatives assessment**

*GPS Risk Assessment Study, Johns Hopkins University Applied Physics Laboratory, VS-99-007, January 1999.

# Incorporation of JHU/APL Study (continued)

- **The airborne GPS interference mitigation techniques are being studied as an option to retaining a ground-based backup**
  - **Cost analysis will compare:**
    - **VOR/DME/ILS backup and the associated VOR/DME/ILS avionics costs**
    - **No ground-based navigation backup, but with the airborne GPS interference mitigation equipage costs**

# Relationship of this Assessment to the NAS Architecture Version 4.0*

- **NAS Architecture 4.0 currently assumes a robust WAAS and LAAS capability and retention of ground-based navaids at the MON level**
- **The NAS Architecture will be updated to reflect the results of this SATNAV Investment Analysis after review and decision by the JRC**

*National Airspace System Architecture, Version 4.0, Federal Aviation Administration, January 1999.

# GPS JPO input on Better GPS Satellite Availability

- **Examined effects of better GPS availability**
  - **Nominal constellation: 24 satellites with conservative outage parameters (21 satellites, 98%)**
  - **Improvement A: 24 satellites with improved outage parameters(24 satellites, 83%)**
  - **Improvement B: 30 satellites with same conservative outage parameters as for nominal (24 satellites, 99.7%)**
- **Observations:**
  - **Improvement A meets en route-NPA availability without the 4th GEO in Alternative IV, and is more conservative than the draft ORD (24 satellites, 95%)**
  - **Service availability is more sensitive to shorter restoration than to a higher number of satellites**

# Performance Assessments

- **Availability of WAAS, LAAS/ELAAS**
- **Assessment of ground-based navaids**

# WAAS, LAAS, and ELAAS Availability--Summary

- **WAAS for En Route through NPA**
  - **Basis for #GEOs and operational restriction estimates**
  - **Sensitivity to GPS constellation availability suggests possible reduction by one GEO in Alternative IV***
- **WAAS NPV and CAT I for Alternatives III and IV**
  - **Basis for #WRSs and operational restriction estimates**
  - **Sensitivities to assumed ionosphere activity and monitoring algorithm and to GPS constellation availability suggest possible reduction in the number of WRSs needed for Alternative IV**

*Would require a change in the current requirement on "average catastrophic-loss probability", which effectively requires three in view

# WAAS, LAAS, and ELAAS Availability--Summary (continued)

- LAAS for CAT I, II, III precision approach
  - Basis for high-availability CAT I to supplement WAAS
  - Sensitivity to GPS constellation availability suggests it may become unnecessary to rely on GEOs or airport pseudolites (APLs) to achieve high CAT I availability
- ELAAS for supplementing en route through CAT I
  - Basis for possible future use of ELAAS to supplement coverage and availability (e.g., in Hawaii, and Alaska) by using repeaters

# Assessment of Ground-Based Navaids

- **Three levels of ground-based navaids are considered**
  - **Full capability: today's number of facilities plus growth**
  - **Minimum Operational-Capability Network (MON*): A reduced network of VOR/DME and ILS facilities that support en route through precision approach operations with some operational restrictions**
  - **Basic Backup Network (BBN*): A significantly reduced network of VOR/DME and ILS facilities that support possible emergency en route through precision approach procedures at selected airports, as well as high-altitude en route operations**
- **Loran C variation for alternatives with MON/BBN**
  - **User option to use Loran C with WAAS/LAAS**

*MON and BBN defined in *Redundant Radionavigation Service in the National Airspace System*, FAA Architecture and System Engineering Directorate, October 1998.; NDBs are also part of the full, MON, and BBN, and will be included in the cost and benefit analyses

# Assessment of Ground-Based Navaids--Summary Results

- Coverage analyses show the following:
  - Very good high-altitude en route coverage even for the smallest VOR/DME network considered (BBN)
  - Low altitude en route coverage is good for MON
  - Low altitude en route coverage is not very good for BBN, but might support emergency procedures to manage traffic in the event of a GPS outage
  - DME/DME (without VOR) terminal operations (for aircraft without inertial) would require adding 25-75 new DME sites, so not recommending cost/benefit analysis
- DME loading analysis showed the following:
  - Potential saturation problem for BBN, but probably OK if larger than BBN or if many GA aircraft do not use DME

# Assessment of Ground-Based Navaids (continued)

- **Operational Implications--Air Carriers:**
  - BBN or MON provides capability to overfly a GPS outage area, and to conduct terminal navigation operations and instrument approaches to the equipped airports
- **Operational Implications--General Aviation:**
  - BBN might support emergency operations to deal with GPS outage; poor low-altitude en route coverage
  - MON supports en route operations between the top airports, but many smaller airports not served with instrument approach capability
  - Possible backup role for Loran C
    - Better en route coverage; NPA for smaller airports
    - Decision on Loran C should consider if BBN or MON already cover airports with most likely jamming threat

# Recommendation: Proceed with Detailed Cost and Benefit Analyses for 12 Cases*

| | Alt. I | Alt. II | Alt. III | Alt. IV |
|---|---|---|---|---|
| ***Baseline Cases*** | **No WAAS, No LAAS Full VOR/DME/ILS** | **NPA WAAS, No LAAS MON VOR/DME, Full ILS** | **WAAS w/vertical, LAAS MON VOR/DME/ILS** | **Robust WAAS, LAAS BBN VOR/DME/ILS** |
| ***Variations on the Baseline Cases*** | • **Full LAAS, BBN ILS** | • **Full LAAS, BBN ILS**<br>• **Baseline plus Loran C** | • **BBN VOR/DME/ILS**<br>• **Baseline plus Loran C** | • **Baseline plus Loran C**<br>• **Airborne GPS RFI mitigation, no BBN**<br>• **No BBN, no airborne GPS RFI mitigation** |

*Airborne equipage assumptions for cost and benefits analyses still being determined, particularly for GPS/WAAS/LAAS equipage rates and backup equipage to include.